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13. Abstract

The objective is to understand the theory of acoustic scattering from rough surfaces, with applications to ocean surfaces.

It is necessary to develop multiple scattering models that are able to treat larger values of roughness, as well as to incorporate as much information as possible into a statistical description of the surface. The mathematical methods we have developed are generic in the sense that they can also be applied to any rough surface. Enhanced backscattering can result when the surfaces are very rough.

We have found additional new results for the coherent (specular) intensity and the backscatter enhancement effect for the direct scattering problem. In addition, we have reconstructed surface profiles from scattered field data using two different approaches.

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FINAL REPORT: Contract number N00014-90-J-1038

TITLE: Rough Surface Scattering

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OBJECTIVE

Understanding the theory of acoustic scattering from rough surfaces, with applications to ocean surfaces.

BACKGROUND

The modelling of direct scattering from rough surfaces has gone beyond simple models such as perturbation theory and the Kirchhoff approximation. Multiple scattering can lead to significant scattering effects, particularly if the surface is very rough. As an example, we point to the enhancement in the backscattering direction. For the inversion problem, however, no one has previously worked out the scattering in the perturbation and Kirchhoff domains.

APPROACH

1. Continued theoretical development of the spectral coordinate (SC) method.
2. Computational solutions using the coordinate coordinate (CC) equation for the direct scattering problem.
3. Solution of surface inversion problems using the SC method in the perturbation and Kirchhoff domains.
4. Further development of approximation methods.

RESULTS

1. For angles away from grazing, the coherent specular intensity is predominantly single scattering even when multiple scattering is occurring.
2. Beyond a certain roughness, the predominant field in the specular direction is incoherent rather than coherent.

3. Surface inversion is possible using the SC method in the perturbation theory domain with an FFT algorithm.

4. Surface inversion is possible using the SC method in the Kirchhoff domain using a restricted data window and an FFT algorithm.

DISCUSSION OF RESULTS

Research was undertaken along both theoretical and computational directions. In the theoretical area the spectral coordinate (SC) method was further developed. This was first published by me in 1985. It is a mixed-representation solution for the rough surface scattering problem, spectral for the scattering amplitude that is directly related to the coordinate dependent boundary values. The overall objective was to insure that the theoretical development was valid for surfaces with very large heights and slopes where backscatter enhancement can occur. The relation of the SC method to both coordinate-coordinate (CC) and spectral-spectral (SS) was also derived, thus yielding a unified theoretical development.

Computationally both the coordinate model for scattering as well as the SC method were used. The direct scattering was done with the coordinate method, the inverse scattering and surface reconstruction with the SC method. For the direct scattering statistical calculations yielded two results. The first is that the coherent scattering is predominantly single scattering even for large roughness. The second is that for large enough roughness the incoherent field in the specular direction is larger than the coherent field. Two methods were used with the SC to find surfaces from the scattered field data. The first used perturbation theory and resulted in an FFT algorithm. The second used the Kirchhoff approximation and a limited aperture of the data to again find an FFT algorithm.

Examples of the coherent return and surface inversion are attached.

PUBLICATIONS

1. "The Reconstruction of Shallow Rough-Surface Profiles from Scattered Field Data," **Inverse Problems, 7,** L7-L12 (1991)(with R.J. Wombell).

2. "Rough Surface Scattering," **Proceedings of the Conference on Directions in Electromagnetic Wave Modeling**, Polytechnic Institute of New York, 1990, in press (with R.J. Wombell).

3. "Rough Surface Scattering," **Waves in Random Media, 1,** S41-S56 (1991) (with R.J. Wombell).

4. "The Reconstruction of Rough-Surface Profiles Using the Kirchhoff Approximation," **J. Opt. Soc. Am. A** (December, 1991) (with R.J. Wombell).

5. "Some Computational Results for Rough Surface Scattering," SPIE **1558 Wave Propagation and Scattering in Varied Media II**, pp. 202-212 (1991) (with R.J. Wombell).

SUBMITTED PAPERS

1. "k-Space Properties of Single- and Double-Layer Potentials and their Derivatives," **Wave Mot.**
2. "Coherent and Incoherent Scattering from Rough-Surfaces," **J. Acoust. Soc. Am.** (with R.J. Wombell).

SUBMITTED BOOKS

Scalar Wave Theory I: Green's Functions and Applications

Publisher: Springer-Verlag, Heidelberg, Germany, Wave Phenomena Series.

HONORS

Invited Presentations:

1. "Rough Surface Scattering," Conference on Directions in Elcctromagnetic Wave Modeling, Polytechnic University, New York, October 23, 1990 (with R.J. Wombell).
2. "The Reconstruction of Rough-Surface Profiles from Scattered Field Data," Conference on Progress in Electromagnetics Research (PIERS), MIT/Boston, July 2, 1991, (with R.J. Wombell).
3. "Scattering from Random Gratings," Conference on Progress in Electromagnetics Research (PIERS), MIT/Boston, July 5, 1991, (with R.J. Wombell).
4. "Some Computational Restuls for Rough Surface Scattering," SPIE Meeting, Technical Conference 1558, San Diego, July 22, 1991, (with R.J. Wombell).

Editor:

Named to the editorial board of the journal "Waves in Random Media," published by the Institute of Physics, U.K.

Chair/Co-Chair:

Sessions 4, 6: Surface Scattering and Remote Sensing I, II — SPIE Meeting, San Diego, CA, July 1991.

PAPERS OR TALKS PRESENTED

1. "Rough Surface Scattering," IMACS 1st International Conference on Computational Physics, Boulder, CO, June 11, 1990, invited presentation (with R.J. Wombell).
2. "Rough Surface Scattering," Conference on Modern Analysis of Scattering Phenomena, Aix en Provence, France, September 7, 1990, invited presentation (with R.J. Wombell).
3. "Rough Surface Scattering," Conference on Directions in Electromagnetic Wave Modeling, Polytechnic University, New York, October 23, 1990, invited presentation (with R.J. Wombell).
4. "The Reconstruction of Rough-Surface Profiles from Scattered Field Data," Conference on Progress in Electromagnetics Research (PIERS), MIT/Boston, July 2, 1991, invited presentation (with R.J. Wombell).
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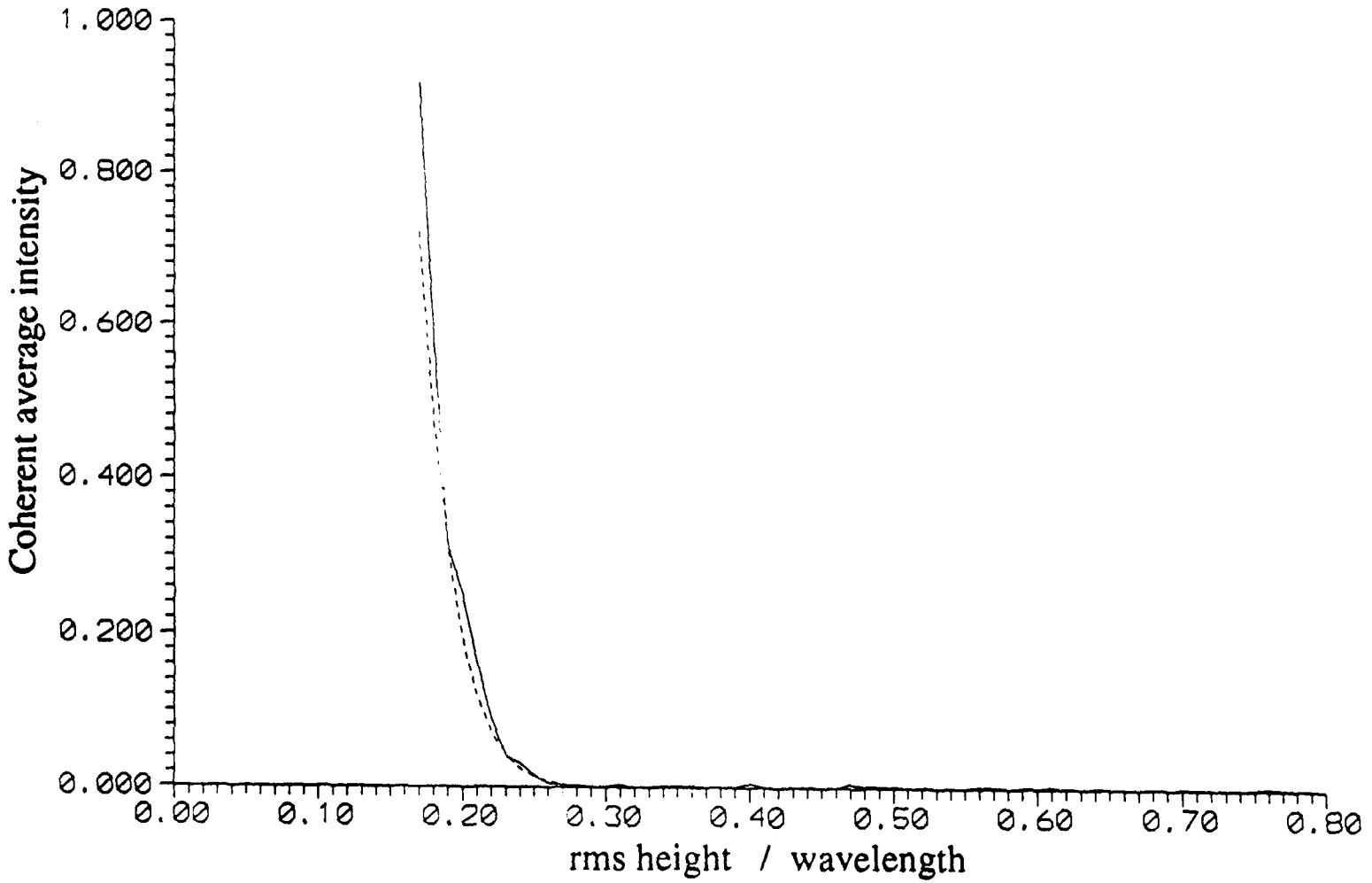

Fig. 1 Ensemble averaged coherent intensity (solid curve) versus single scattering coherent intensity (dashed curve) for 30° incidence.

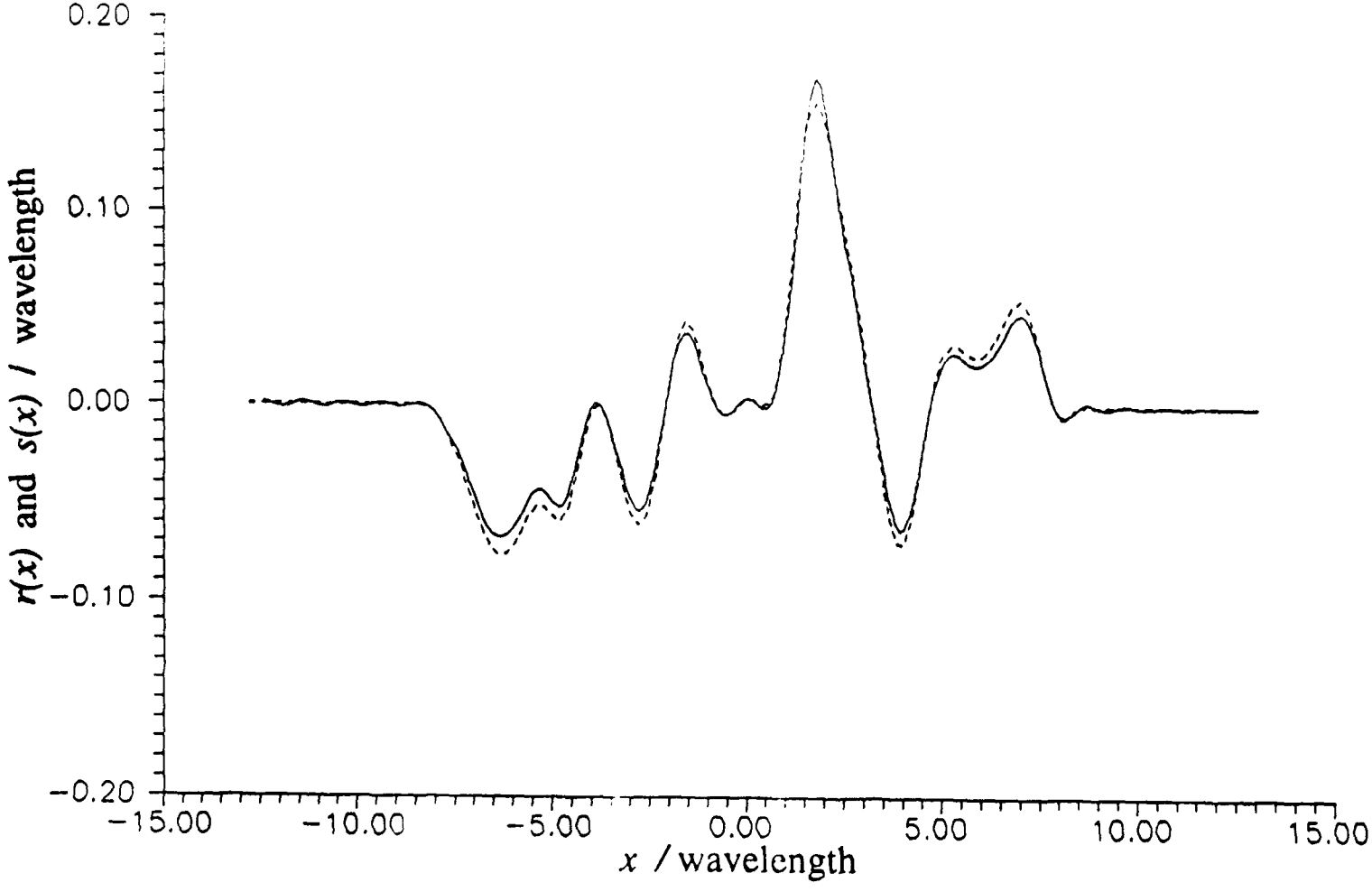

Fig. 2 The reconstruction $r(x)$ (full curve) of a surface profile $s(x)$ (broken line) in perturbation theory using an FFT algorithm.

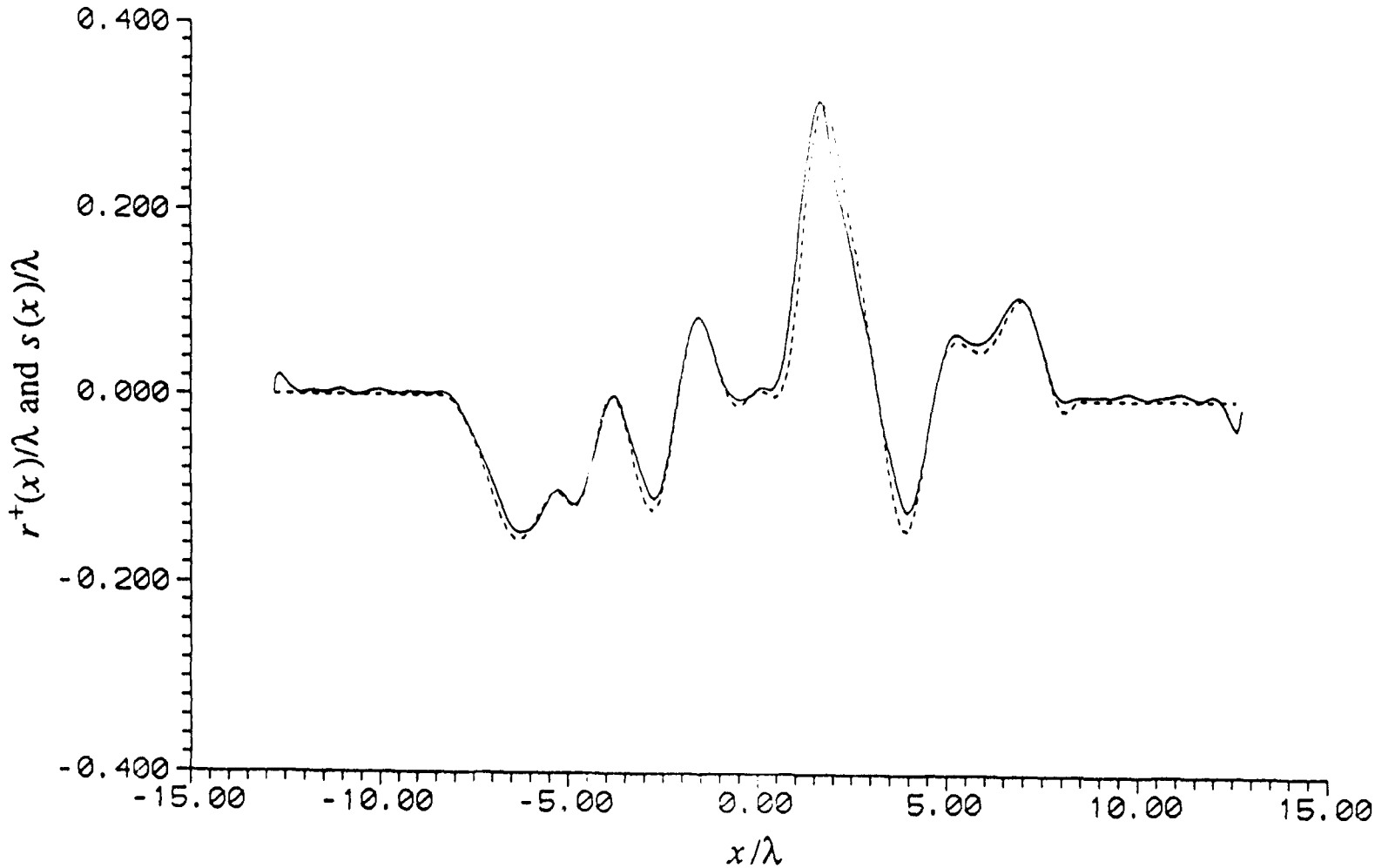

Fig. 3 The reconstruction $r^+(x)$ (full curve) of a surface profile $s(x)$ (broken line) in the Kirchhoff approximation using angle restricted data and an FFT algorithm.